Interview Guidebook

for

Engineering Services Examination,
State Engineering Services, PSUs and
other competitive examinations

Electronics and Telecommunication Engineering

Part-I : Theory

Interview oriented concise theory, definitions,
concepts and formulae

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Interview Guidebook

Part - I : Theory

Interview oriented concise theory, definitions, concepts and formulae

E&T Engineering

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UNIT 1

Basic Electronics Engineering and Analog Circuits

Semiconductor Physics

Field Intensity

The force experienced by a unit positive charge under the influence of an electric field is known as the electric field intensity at that point.

If a charge of q Coulomb is kept in an electric field at a point and the force experienced by the charge is F(Newtons) then the electric field intensity at that point is given by:

$$E = \frac{F}{q} \text{ (N/C)}$$

Potential

Potential, V(volts) of a point B with respect to point A is the work done against the field in taking a unit positive charge from A to B.

Consider if A is at x_0 and B is at an arbitrary distance x, if follows that

$$\boxed{V \equiv -\int_{x_0}^{x} E \cdot dx}$$

$$\boxed{E = -\frac{dV}{dx}}$$

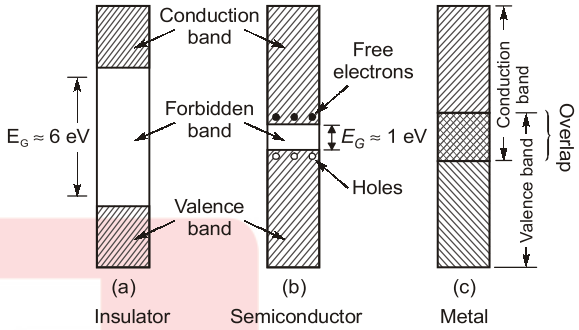
- The negative sign shows here that the electric field is directed from the region of higher potential to the region of lower potential.
- Electric field intensity is a vector quantity while potential is a scalar quantity.

The eV unit of Energy

The joule (J) is the unit of energy in the MKS system. However, in electronics engineering problems, the joule is too large a unit. So practical unit for the energy in electronics engineering is **electron volt (eV)** and is defined as the energy gained by the electron in moving through a potential difference of 1V i.e.

$$\boxed{1\,\text{eV} = 1.6 \times 10^{-19} \text{ (Joule)}}$$

Insulators, Semiconductors and Metals



Insulators

- It has a very wide forbidden-energy gap ($\simeq$ 6 eV) separating the filled valence region from the vacant conduction band. Because of this, it is practically impossible for an electron in the valence band to jump the gap, reach the conduction band.
- At room temperature, an insulator does not conduct. However, it may conduct if its temperature is very high or if a high voltage is applied across it. This is termed as the **breakdown of the insulator.**
- **Example:** diamond.

Semiconductors

- At 0°K semiconductor materials have the same structure as insulators except the difference in the size of the band gap E_G, which is much smaller in semiconductors ($E_G \simeq 1$ eV) than in insulators.
- The relatively small band gaps of semiconductors allow for excitation of electrons from the lower (valence) band to the upper (conduction) band by reasonable amount of thermal or optical energy.
- The difference between semiconductors and insulators is that the conductivity of semiconductors can increase greatly by thermal or optical energy.
- **Example:** Ge and Si.

Metals

- Without supplying any additional energy such as heat or light, a metal already contains a large number of free electrons and that is why it works as a good conductor.
- **Example:** Al, Cu etc.

Semiconductor Materials: Ge, Si and GaAs

Single crystal and compound crystal semiconductor are two classifications of semiconductor depending upon number of constitutional elements. Examples of single crystal semiconductors are germanium (Ge) and silicon (Si) whereas compound semiconductors are gallium arsenide (GaAs), cadmium sulphide (CdS), gallium nitride (GaN) and gallium arsenide phosphide (GaAsP) etc.

Intrinsic Materials and Covalent Bonding

Semiconductor in its purest form (without any impurity) is known as **intrinsic semiconductor**.

An intrinsic semiconductor (such as pure Ge or Si), has only four electrons in the outermost orbit of its atoms. A covalent bond consists of two electrons, one from each adjacent atom. Both the electrons are shared by the two atoms. At absolute zero, all the valence electrons are tightly bound to the parent atoms. No free electrons are available for electrical conduction. **The semiconductor therefore behaves as a perfect insulator at absolute zero.**

Charge Carriers in Intrinsic Semiconductor

At room temperature (say 300°K) sufficient thermal energy is supplied which is sufficient for breaking the covalent bonds. When a covalent bond is broken it produces a electron and a hole. Free electrons and holes are always generated in pairs. Therefore, the concentration of free electrons and holes will always be equal in an intrinsic semiconductor

$$\boxed{n = p = n_i}$$

where n_i is called the intrinsic concentration.

Note:

Although, strictly speaking, a hole is not a particle; for all practical purposes we can view it as a positively charged particle capable of conducting current. This concept of a hole as a positively charged particle merely helps in simplifying the explanation of current flow in semiconductors.

Effect of Temperature on Conductivity of Intrinsic Semiconductor

If we raise the temperature, more electron hole pairs are generated. The higher the temperature, the higher is the concentration of charge carriers. As more charge carriers are made available, the conductivity of intrinsic semiconductor increases with temperature. In other words, the resistivity (inverse of conductivity) decreases as the temperature increases. That is; semiconductor have negative temperature coefficient of resistance.

Extrinsic Semiconductor Materials

A doped semiconductor is called an extrinsic semiconductor.

Doping is the process to create carriers in semiconductors by purposely introducing impurities into the crystal.

n-type semiconductor

An n-type semiconductor is created by introducing impurity elements that have five valence electrons (pentavalent), such as antimony, arsenic and phosphorus. The pentavalent impurity atom forms four covalent bonds with neighbouring four silicon atoms, however an additional fifth electron in the impurity atom, which is unassociated with any particular covalent bond. This remaining electron loosely bound to its parent atom, is relatively free to move within the newly formed n-type material.

p-type semiconductor

The p-type semiconductor is formed by doping a pure germanium or silicon crystal with impurity atoms having three valence electrons. The elements most frequently used for this purpose are boron, gallium and indium.

Note that there is now an insufficient number of electrons to complete the covalent bonds of the newly formed lattice. The resulting vacancy is called a hole and is represented by a small circle or a plus sign, indicating the absence of a negative charge. The resulting vacancy will readily accept a free electron;

Transport Phenomena in Semiconductors

Mobility

If a constant electric field, say E(Volts/m) is applied. As a result of electrostatic force, the electrons would be accelerated and the velocity would increase indefinitely with time, were it not for the collisions with the ions. However, at each inelastic collision with an ion, an electron losses energy, and a steady state condition is reached where a finite value of speed called **drift speed v** is attained. Hence the average speed v is proportional to E.

Thus,

$$\boxed{v = \mu E}$$

where μ (square meters per volt-second) is called the **mobility** of the electrons.

- Mobility of charge carriers is a measure of how quick electron (or hole) move from one place to another.
- Electron mobility is always greater than hole mobility and therefore the electron can travel fast and contribute more current than a hole.
- For larger electric field intensities, the mobility of charge carriers will be very small and therefore the drift velocity of charge carriers will remain almost a constant.
- Mobility of charge carrier decreases with temperature
- Higher the mobility more is the material suitable for high frequency applications.

Conductivity

- Conductivity is the reciprocal of resistivity.
- Conductivity denotes current carrying capacity of the material or device. Units $\rightarrow \mho m^{-1}$ or Sm^{-1}.

Conductivity Vs Temperature

- In metals resistivity of metal increases with increase in temperature. So conductivity of metals decreases with increase in temperature.
- In semiconductors conductivity mainly depends upon number of charge carriers. So in a semiconductor conductivity increases with temperature.

Current

It is defined as the flow of charge per unit time through a conducting medium. In metals current is carried by only electrons while in case of semiconductors it is carried by both electrons and holes.

Drift Current

It is the flow of current through the material or device under the influence of voltage or field intensity.

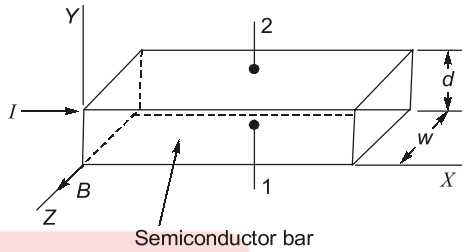
Diffusion Current

Any spatial variation (gradient) in n and p calls for a net motion of the carriers from the region of high carrier concentration to regions of low carrier concentration. This type of motion is called diffusion and represents an important charge transport process in semiconductors.

The Hall effect

If a specimen (metal or semiconductor) carrying a current I is placed in a transverse magnetic field B, an electric field E is induced in the direction perpendicular to both I and B. This phenomenon, known as the Hall effect, is used to determine whether a semiconductor is n- or p-type and to find the carrier concentration. Also, by simultaneously measuring the conductivity σ, the mobility μ can be calculated.

Consider the figure shown below. Here current I is in $+x$-direction, magnetic field B is in $+z$ direction then induced electric field will be in '–' ve y-direction.



Applications

Hall effect is used in many applications as following:

- measurement of magnetic flux density.
- measurement of displacement.
- measurement of current.
- measurement of power in Electro-magnetic waves.
- determination of carrier concentration.
- determination of mobility of semiconductor material.

Note:

- Hall coefficient, $R_H \propto$ Temperature coefficient of resistance of given specimen.
- For metals, σ is larger, V_H is small.
  For semiconductors, σ is small, V_H is large.
- Hall effect is used to determine whether a semiconductor is n or p-type, to find the carrier concentration, conductivity (σ) and mobility (μ) can also be calculated.

The Fermi level

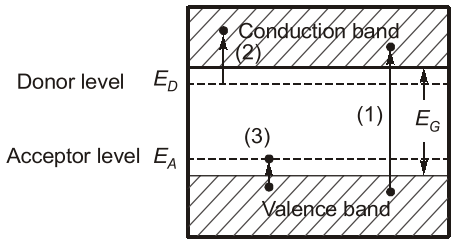
The function $f(E)$, the **Fermi-Dirac distribution function**, gives the probability that an available energy state at E will be occupied by an electron at absolute temperature T.

The quantity E_F is called the **Fermi level.**

- The Fermi level E_F is the energy below which probability of finding an electron is 1 at $T = 0$ K.
- The Fermi level E_F is the energy at which probability of finding an electron is 0.5 at any value of T.

Photoconductors

Consider the energy diagram of a semiconductor having both acceptor and donor impurities. If photons of sufficient energy illuminate this specimen, photogeneration takes place and the following transitions are possible.



Transition (1) : Electron-hole pair can be created by a high-energy photon, in which is called intrinsic excitation.

Transition (2), (3) : A photon may excite a donor electron into the conduction band (2) and this may also excite a valence electron to acceptor state (3), these transitions are called extrinsic excitation.

Density of states in conduction band and valence band is greater than that of impurity states (photoconductivity is due principally to intrinsic excitation).

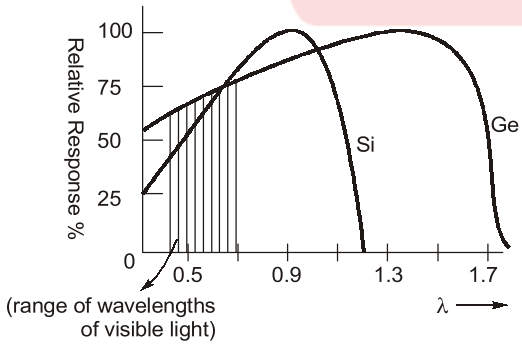
- *Spectral response :* λ_c corresponding to energy gap E_G is expressed as

$$\lambda_c = \frac{1.24}{E_G}$$

$\lambda_c \rightarrow$ Expressed in microns
$E_G \rightarrow$ Electron volts

For Si, $E_G = 1.1$ eV and $\lambda_c = 1.13\,\mu m$
For Ge, $E_G = 0.72$ eV and $\lambda_c = 1.73\,\mu m$
} at room temperature

Relative spectral response



- Photoconductor is frequency selective device.

Commercial Photoconductive cells

- Photoconductive device with the widest application is the cadmium sulfide cell (CdS).
- The sensitive area of this device consists of a layer of chemically deposited CdS which may contain impurities like silver, antimony or indium.
- In absolute darkness, resistance ≈ 2 MΩ and in strong light illumination resistance ≈ 10 Ω.
- These photoconductors are designed to dissipate safely 300 mW and can be made to handle safely several watts. Hence CdS photoconductor can operate a relay directly without intermediate amplifier circuits.
- PbS cell has a peak on the sensitivity curve at 2.9 μm, hence is used for infrared detection or infrared absorption measurements
- Selenium cell is sensitive through the visible end, and particularly toward the blue end of the spectrum.

Semiconductor Diode

If we join a piece of p-type material to a piece of *n*-type material such that the crystal structure remains continuous at the boundary, a pn-junction is formed. Such a pn-junction makes a very useful device. It is called a semiconductor (or crystal) diode. There are two types of pn junction.

- **Step graded junction:** Here, there is an abrupt change of charge concentration from *p* side to *n* side across the junction.
- **Linear graded junction:** Here, there is a gradual change of charge concentration from *p* side to *n* side across the junction.

PN Junction Theory

When no bias is applied

When no external voltage is connected to the *pn*-junction. As soon as pn-junction is formed the following processes are initiated:

- Holes from the p-region diffuse into the n-region. They then combine with the free electrons in the n-region.
- Free electrons from the n-region diffuse into the *p*-region. These electrons combine with the holes.
- The diffusion of holes and electrons takes place because there is a difference in their concentrations in the two regions.
- After a few recombinations of holes and electrons in the immediate neighborhood of the junction, a restraining force is setup automatically. This force is called a **barrier.** Further diffusion of holes and electrons is stopped by this barrier.
- Electric current can not flow since no circuit has been connected to the pn-junction. The drift of minority carriers across the junction is counter balanced by the same number of majority carriers across the junction.

These few majority carriers have sufficiently high kinetic energy to overcome the barrier and cross the junction. In fact, the barrier height adjusts itself so that the flow of minority carriers is exactly balanced by the flow of majority carriers across the junction.

Forward-bias condition ($V_D > 0$ V)

A forward-bias or "on" condition is established when positive terminal of battery is connected to the p-type material and negative terminal to the n-type material.

Due to applied forward bias the diffusion of the carriers that is electrons from *n* to *p* side and holes from *p* to *n* side take place. The diffusion of the carriers produces a large forward current. As the applied bias increases in magnitude, the depletion region will continue to decrease in width until a flood of electrons can pass through the junction, resulting in an exponential rise in the forward current.

Reverse-bias condition ($V_D < 0$ V)

If an external potential is applied across the *pn*-junction such that the positive terminal is connected to the *n*-type material and negative terminal is connected to the *p*-type material. The number of uncovered ions will increase due to the large number of free electrons/holes drawn to the respective potential of the applied voltage. The net effect, therefore, is a widening of the depletion region. As a result majority carriers can not cross the barrier, effectively reducing the majority current flow to zero. The number of minority carriers however, entering the depletion region will not change, resulting in minority-carrier flow across the junction.

The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by I_s or I_0.

- Also called as minority carrier current or leakage current or thermally generated current.
- If leakage current is small, the device will have very good thermal stability.
- It is highly sensitive to temperature. It doubles for every 10°C rise in temperature for both Si and Ge.

Note:

- Leakage current for

Ge	Diode	:	μA
Si	Diode	:	nA

The greatest advantage of Si is smaller leakage currents.

Cut-in voltage (V_γ)

It is the minimum forward voltage required so that the forward current flows through the diode. Cut-in voltage is also known as:

- Offset voltage
- Threshold voltage
- Knee voltage
- Break voltage

Cut-in voltage decreases with temperature. For 1°C rise in temperature, it is reduced by 2.5 mV.

Space-charge or Transition Capacitance C_T

A reverse bias causes majority carriers to move away from the junction, thereby uncovering more immobile charges. Hence the thickness of the space-charge layer at the junction increases with reverse voltage. This increase in uncovered charge with applied voltage may be considered a capacitive effect.

Diffusion Capacitance or Storage Capacitance

When forward bias is applied across the diode then the diffusion of the carriers take place. The amount of diffused carriers is exponentially related to the applied voltage. Thus, if the applied voltage is changed by *dV* then the amount of diffused charges will also change producing *dQ*. Thus, there is capacitance effect seen in forward bias diode.

Breakdown Diodes

Diodes which are designed with adequate power-dissipation capabilities to operate in the breakdown region may be employed as voltage-reference or constant voltage devices. Such diodes are known as avalanche, breakdown, or Zener diodes.

Two Phenomenon of Breakdown

Avalanche breakdown: A thermally generated carrier (part of the reverse saturation current) falls down the junction barrier and acquires energy from the applied potential. This carrier collides with a crystal ion and imparts sufficient energy to disrupt a covalent bond. In addition to the original carrier, a new electron-hole pair has now been generated. Thus each new carrier may in turn, produce additional carriers through collision and the action of disrupting bonds. This cumulative process is referred to as avalanche multiplication. It results in large reverse currents, and the diode is said to be in the region of avalanche breakdown.

- Breakdown voltages are greater than 6 V.
- Avalanche breakdown voltages increases with temperature. i.e. positive temperature coefficient.

Zener breakdown: It is possible to initiate breakdown through a direct rupture of the bonds. Because of the existence of the electric field at the junction, a sufficiently strong force may be exerted on a bound electron by the field to tear it out of its covalent bond. The new hole-electron pair which is created increases the reverse current. Note that this process, called Zener breakdown, does not involve collisions of carriers with the crystal ions (as does avalanche multiplication).

It is found that Zener breakdown occurs at a field of approximately 2×10^7 V/m. This value is reached at voltages below about 6 V for heavily doped diodes. For lightly doped diodes the breakdown voltage is higher, and avalanche multiplication is the predominant effect.

Zener breakdown voltage decreases with the temperature. i.e. negative temperature coefficient.

Tunnel Diode

Tunnel diode is basically a p^+ n^+ semiconductor where the depletion layer width is very narrow (100 Å – 200 Å). The current in the device flow due to tunneling phenomenon.

Applications

- High speed switch
- High frequency oscillator
- The most commonly available tunnel diodes are made from Ge or GaAs.

Advantages

Low cost, low noise, simplicity, high speed, environmental immunity and low power.

Disadvantages

- Low output-voltage swing.
- Two-terminal device; because the tunnel diode is a two terminal device, there is no isolation between input and output and this leads to serious circuit design difficulties.



Tunnel Diode

Varactor Diode

Varactor diode is a linear graded diode. Its principle of operation is transition capacitance. It is always operated under reverse bias condition. Transition capacitance (C_T) is given by

$$C_T \propto V^{-n}$$

Applications

Varactor diode is a low noise microwave device. It is fabricated with GaAs. Following are the applications of varactor diode:

- For direct generation of FM by using varactor diode modulator circuit.
- For fine tuning of receivers.
- For self balancing of bridges.
- As a PARA-amplifier (parametric amplifier) and it is low noise microwave power amplifier used in satellite communication.



Varactor Diode

PIN Diode

PIN diode is a microwave switch. In PIN diode the intrinsic semiconductor is sandwiched in between highly doped P and highly doped N regions. PIN diodes offer very small switching times. The smaller switching times are due to high resistivity of intrinsic layer.

- PIN diode is a two-terminal device and having a single junction.
- It is always operated under reverse bias condition.
- PIN diode is basically a passive microwave diode. It can be used to handle large amount of power, as a microwave mixer, as a microwave demodulator, as a microwave limiter and also used in MPST (Multi Pole Single Through) and MPMT switches. It can also be used in designing of microwave duplexers.

Diode Circuits

Rectifier Circuits

- Rectification is the process of converting an alternating (AC) voltage into one that is limited to one polarity. The diode is useful for this function because of its non linear characteristics, that is current exists for one voltage polarity, but is essentially zero for the opposite polarity. Rectification is classified as half-wave or full-wave, with half wave being the simpler and full-wave being more efficient.
- A diode rectifier forms the first stage of a dc power supply.

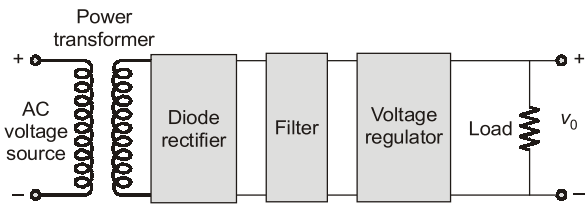


Diagram of an electronic power supply

Note:

- Various Definition and Important Points Related to rectifier:

  (i) **Regulation:** The variation of dc output voltage as a function of dc load current is called regulation. The percentage regulation is defined as

  $$\% \text{ regulation} = \frac{V_{\text{no load}} - V_{\text{load}}}{V_{\text{load}}} \times 100\%$$

  where no load refers to zero current and load indicates the normal load current. Ideally it should be zero.

  (ii) **Peak Inverse Voltage (PIV):** The peak inverse voltage (PIV) [or PRV (peak reverse voltage)] is the voltage rating that must not be exceeded in the reverse-bias region or the diode will enter the Zener avalanche region.

- A full-wave rectifier allows unidirectional (one-way) current through the load during the entire 360° of the input cycle, whereas a half-wave rectifier allows current through the load only during one-half of the cycle.

Types of Full-wave Rectifiers

The Centre-Tapped Full-wave Rectifier

A centre-tapped rectifier is a type of full-wave rectifier that uses two diodes connected to the secondary of a centre-tapped transfer. The input voltage is coupled through the transformer to the centre-tapped secondary. Half of the total secondary voltage appears between the centre tap and each end of the secondary winding.

The Bridge Full-Wave Rectifier

The bridge rectifier uses four diodes which are connected in such a way that they form a bridge structure. The output obtained at the load is full-wave rectified version of input.

Comparison of Rectifier Circuits With Resistive Load

Comparison of rectifier circuits with resistive load

		HW	Centre tapped FW	Bridge
1.	No. of diodes	1	2	4
2.	Secondary voltage line to line	V	2 V	V
3.	Peak inverse voltage (Max. reverse voltage that occurs across the diodes)	V_m	2 V_m	V_m
4.	No load DC output V_{DC}	V_m/π	2 V_m/π	2 V_m/π
5.	Ripple factor	1.21	0.482	0.482
6.	Ratio of rectification	0.406	0.812	0.812
7.	Transformer utilization factor	0.287	0.693	0.812
8.	Ripple frequency	f	$2f$	$2f$

Filters

- An inductor filter has a ripple that increase with load resistance and consequently used with relatively high load currents.
- The ripple from a capacitor filter decreases as the load resistance increases and provides effective filtering only for light loads of 50 mA and less.

Clippers

Clipper circuits, also called limiter circuits are used to eliminate portions of a signal that are above or below a specified level. For example, the half-wave rectifier is a clipper, since all voltages below zero are eliminated. A simple application of a clipper is to limit the voltage at the input to an electronic circuit so as to prevent breakdown of the transistors in the circuit.

Clampers

A clamper adds a D.C. level to an A.C. voltage. Clampers are sometimes known as D.C. resonators. The circuit that adds a positive D.C. level is called a positive clamper and circuit that adds a negative D.C. level is called a negative clamper.

Bipolar Junction Transistors (BJTs)

The three terminal devices are far more useful than two terminal ones, because they can be used in a multitude of applications, ranging from signal amplification to the design of digital logic and memory circuits. The basic principle involved is the use of the voltage between two terminals to control the current flowing in the third terminal. In this way, a three-terminal device can be used to realize a controlled source, which is the basis for amplifier design.

Device Structure and Mode of Operation

(a) Doping

- Emitter is of maximum doping (emits majority charge carriers).
- Base is the most lightly doped (to minimize recombination).
- Collector is relatively less doped in comparison to emitter region.

(b) Width

- Base width is minimum (to reduce the recombination).
- Collector width is maximum (to minimize heat dissipation per unit surface area).
- Emitter → medium width.

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Electronics and Telecommunication Engineering

Part-II

Topicwise Bifurcated

Previous Interview Questions and Practice Questions

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UNIT 1

Basic Electronics Engineering and Analog Circuits

1. Semiconductors

1.1 What is an Integrated Circuit?

Ans. An integrated circuit (IC), also called a microchip, is an electronic circuit etched onto a silicon chip. Its main advantages are low cost, low power, high performance, and very small size.

1.2 Name some semiconductor devices? Have you used them?

Ans. They are light emitting diode, varactor diodes, tunnel diode, laser diode.

1.3 What is a conductor?

Ans. A substance, body, or device that readily conducts heat, electricity, sound, etc. Copper is a good conductor of electricity.

1.4 What is a semiconductor?

Ans. A semiconductor is a solid material that has electrical conductivity in between that of a conductor and that of an insulator.

1.5 What will be the polarity on a *p*-type semiconductor?

Ans. A *p*-type semiconductor is electrically neutral.

1.6 What is thermal voltage?

Ans. Thermal voltage is the voltage equivalent of temperature. At 0 K, electrons in a semiconductor are at rest. If temperature is increased, the electrons gain energy proportional to temperature and this voltage can be expressed as Energy/Coulomb.

1.7 What is diffusion current?

Ans. Diffusion current is a current in a semiconductor caused by diffusion of charge carriers (holes, electrons).

1.8 What is energy band gap?

Ans. It is an energy range in a solid where no electron state can exist. It is a major factor in determining conduction of a material.

1.9 Why does a Germanium Controlled Rectifier (GCR) not exist?

Ans. No doubt Germanium devices have a speed faster than silicon devices but Ge devices can't withstand high temperature and their reverse saturation current is also very high so Ge is not preferred over Si devices.

1.10 Give three examples of Trivalent and Pentavalent impurities.

Ans. Trivalent Impurities are Boron, Aluminium and Gallium while Pentavalent Impurities are Phosphorus, Arsenic and Antimony.

1.11 Can a semiconductor doped n-type, 10^{25} cm^{-3} and then p-type up to the same concentration, 10^{25} cm^{-3}, be called intrinsic from mobility consideration?

Ans. No, such an impurity compensated semiconductor will have a very low mobility because of high carrier-carrier scattering.

1.12 What is a degenerate semiconductor?

Ans. A heavily doped semiconductor, in which the Fermi level lies in the conduction or valence band so that material behaves as a metal, is known as degenerate semiconductor.

1.13 Given two semiconductors, Si and GaAs, which has a higher temperature of operation?

Ans. Since GaAs has higher E_g which implies more energy is required to remove an electron from a valence band. Therefore, the intrinsic temperature of material is higher. So GaAs can withstand higher temperature.

1.14 The Einstein formula $\frac{D}{\mu} = \frac{kT}{q}$ is not applicable to which type of semiconductor?

Ans. Degenerate semiconductor because in this type of semiconductor Fermi-level is within conduction band or valence band.

1.15 What is the two valley model of GaAs?

[ESE-2005]

Ans. According to energy band theory of *n*-type GaAs, a high mobility lower valley is separated by an energy of 0.36 eV from a low mobility upper valley. Electron densities in the valleys remain the same under equilibrium. When an electric field greater than that of lower valley is applied, the electrons begin to transfer to the upper valley and all the electrons are transferred to upper valley if applied electric field is further increased. This model signifies negative differential mobility.

1.16 Why does mobility decrease in GaAs, when a very high electric field is applied?

[ESE-2005, 2022]

Ans. With GaAs and InP, the high-field behaviour of the drift-velocity does not follow the common pattern of saturation but actually the drift-velocity reaches a peak and then starts to decrease. This is because the band structure in these materials has more than one local minima in the conduction band. The lowest conduction band minima is at the same point ($k = 0$). At this point the electrons have a low effective mass and a high mobility. A second local minimum occurs at the edge of the Brillouin zone and is 0.36 eV higher. This minimum has a higher effective mass and therefore a lower mobility. At low electric-fields, nearly all of the conduction electrons will occupy the lower minimum at k =0 with the lesser effective mass and high mobility. If the electric-field is increased gradually to about 3.2 kV cm^{-1} , the electrons will have enough energy to occupy energies in the second minima with its associated higher effective mass and lower mobility. As the field is increased further, the proportion of electrons with the lower mobility increases and the drift-velocity will continue to decrease until all the electrons share the lower mobility and the drift-velocity will level off.

1.17 What happens if doping is high?

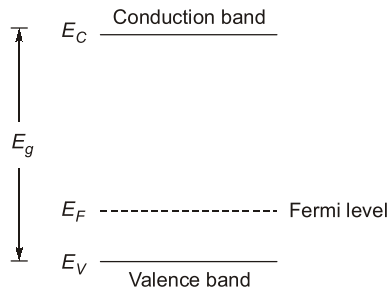
[ESE-2006]

Ans. If a semiconductor is doped to high levels, then it starts to act more like a metal than as a semiconductor. It is known as a degenerate semiconductor.

1.18 Can you draw the energy band diagram for p-type semiconductor?

[ESE-2006]

Ans.



Energy band diagram of *p*-type semiconductor

1.19 Do Ge and Si have different Fermi level?

[ESE-2013]

Ans. In intrinsic semiconductor, the Fermi level is placed in the middle of conduction and valence band. Since Si and Ge have different values of band gap, thus their Fermi level is also different.

1.20 Why are semiconductors used in electronics?

[ESE-2013]

Ans. Semiconductor devices are electronic components that exploit the electronic properties of semiconductor materials, principally silicon, germanium, and gallium arsenide, as well as organic semiconductors. Semiconductor devices have replaced thermionic devices (vacuum tubes) in most applications. They use electronic conduction in the solid state as opposed to the gaseous state or thermionic emission in a high vacuum. Semiconductor materials are useful because their behavior can be easily manipulated by the addition of impurities, known as doping. Semiconductor conductivity can be controlled by introduction of an electric or magnetic field, by exposure to light or heat, or by mechanical deformation of a doped monocrystalline grid; thus, semiconductors can make excellent sensors. Doping a semiconductor such as silicon with a small amount of impurity atoms, such as phosphorus or boron, greatly increases the number of free electrons or holes within the semiconductor. When a doped semiconductor contains excess holes it is called "p-type", and when it contains excess free electrons it is known as "n-type", where p (positive for holes) or n (negative for electrons) is the sign of the charge of the majority mobile charge carriers. The semiconductor material used in devices is doped under highly controlled conditions in a fabrication facility, or fab, to precisely control the location and concentration of *p* and *n*-type dopants. The junctions which form where n-type and *p*-type semiconductors join together are called *p*-*n* junctions.

1.21 Can Si be used as LED material? [ESE-2014]

Ans. Silicon is an indirect band gap semiconductor and cannot be used as LED material. However, photodetectors are mostly made using silicon.

1.22 Do you know about InP? Where is it used? [ESE-2014]

Ans. Indium phosphide is a binary semiconductor composed of indium and phosphorus. It is used in high power and high frequency electronics because of its superior electron velocity. It is a direct band gap semiconductor and is used in optoelectronic devices like laser diodes.

1.23 What will be the effect of electron scattering on mobility? [ESE-2015]

Ans. The effect of lattice scattering of electrons is to reduce the mobility with increase in temperature. This can be understood qualitatively by seeing that as the temperature increases the atomic vibrations increase and at the same time the electrons also travel faster. Both these effects combine to reduce the mobility

1.24 What is the ratio of μ_n/μ_p in silicon? [ESE-2016]

Ans. Electron mobility for Si = 1400 cm^2/V-s
Hole mobility for Si = 450 cm^2/V-s
Ratio = 3.11.

1.25 Semiconductor works as an insulator under which condition? [ESE-2016]

Ans. When all electrons are in the valence band, i.e., at 0 K.

1.26 How does semiconductor contribute in conduction? [ESE-2016]

Ans. A pure **semiconductor** has four valence electrons. It shares the four with its neighbour by bonding atoms. So some external energy is needed to break bond. When at room temperature the bond breaks and only some electrons **can** become free at room temperature.

1.27 Can insulator work as a conductor? [ESE-2016]

Ans. All insulators become electrically conductive when a sufficiently large voltage is applied that the electric field tears electrons away from the atoms. This is known as the breakdown voltage of an insulator.

1.28 Why is Si preferred over Ge? [ESE-2016, 2017, 2022]

Ans. First reason is that Si forms on its surface very easily a thin layer of SiO2 which is a very good insulator and which technologically can be very easily processed. Second reason is that Si has a larger band-gap (0.7 eV) than Ge (0.2 eV) and because of this, the phenomenon of thermal pair generation is smaller in Si than in Ge. This means that at the same temperature the noise of the Si devices is smaller than the noise of Ge devices and also that the reverse current of a p-n junction is smaller for Si than for Ge. Third reason is that Si is widely encountered in nature in the form of sand, from which it is extracted by reduction with carbon. In contrast Ge is not so easily found in nature, and when found is encountered only in chemical compounds that it forms because of its high reactivity.

1.29 Why does Si absorb light but does not emit light? [ESE-2016]

Ans. As silicon is an indirect semiconductor when an electron makes a transition top of valence band is not just below the bottom of conduction band due to which it collides and dissipate energy in the form of heat. Bandgap of silicon is 1.1 eV.

1.30 Which wavelengths Si will absorb? [ESE-2016]

Ans.
$$\lambda \le 1.24/E_g$$
$$\le 1.24/1.1$$
$$\le 1.127 \text{ micrometer}$$

1.31 What is physical significance of continuity equation? [ESE-2016]

Ans. The continuity equation says that if charge is moving out of a differential volume (i.e. divergence of current density is positive) then the amount of charge within that volume is going to decrease, so the rate of change of charge density is negative. Therefore, the continuity equation amounts to a conservation of charge.

1.32 What is the value of hole mobility in silicon? [ESE-2016]

Ans. The hole mobility of Si is around 450 cm^2/ (Vs).

1.33 What is Fermi level? [ESE-2013, 2017]

Ans. Fermi level is a term used to describe the top of the collection of electron energy levels at absolute zero temperature. The Fermi level is the energy below which probability of finding an electron is 1 at 0 K.

1.34 Why mobility of electrons is greater than that of holes? [ESE-2015, 2016, 2017]

Ans. Hole is a vacancy where an electron was in a bound state. Movement of this hole happens when another bound electron "jumps" to this vacant state (the jump may be due to an electric field) and this causes a vacancy where the "jumping" electron was present before. Thus the vacancy has now moved. Mobility is the speed (velocity) of movement of a particle (an electron or a hole) per unit Electric field (in low field situations). So this movement of vacancies (hole) is 'harder' than the movement of electrons, which are not in bound states.

Electrons have more mobility than holes. The mobility is proportional to the carrier relaxation time and inversely proportional to the carrier effective mass.

The electron mobility is often greater than hole mobility because quite often, the electron effective mass is smaller than hole effective mass.

1.35 What is hole? Is it real or virtual? What is hole current? Is it real or virtual? How virtual hole (concept) gives real hole current? [ESE-2014, 2017]

Ans. The absence of electron in a particular place in an atom is called as hole. It is virtual. The current constituted by the movement of holes or electrons of the valence band through holes is called hole current.

Hole current is a real phenomenon because when an external electric field is applied, the valence band electrons start moving in a direction opposite to the electric field through holes, which constitutes a real component of current called hole current.

1.36 How are conduction and valence bands defined? How does current flow take place using conduction and valence bands? How do electrons move in the conduction band and holes in the valence band? [ESE-2017]

Ans. The range of permissible energy values which an electron in a solid material can have that allows the electron to dissociate from a particular atom and become a free charge carrier in the material. The range of permissible energy values that are the highest energies an electron can have and still be associated with a particular atom of a solid material

In the conduction band, free electrons move in the direction opposite to an applied electric field, but in the valence band, the hole moves in the direction of the electric field.

1.37 How does conduction take place in a semiconductor? [ESE-2017]

Ans. When temperature is 0 degree Kelvin the semiconductor behaves as an insulator. But on an increase in temperature, some covalent bonds get broken and free electron and hole pairs are generated. The availability of free electrons in the conduction band and holes in the valence band gives rise to conduction on applying an external field.

1.38 What is a hole? How does current flow in a semiconductor? Which Field influences motion of electrons and holes? [ESE-2017]

Ans. The absence of an electron in a particular place in an atom is called a hole. A hole is an electric charge carrier which has a positive charge. The electric charge of a hole is equal to the electric charge of an electron but has opposite polarity.

At room temperature, a covalent bond will be broken and the electron will jump from the valence band to the conduction band. The vacancies in the valence band are holes which will also contribute in the process of conduction. When an external electric field is applied, the hole in the valence band will travel in the direction of the electric field and the electron of the conduction band will travel in the direction opposite to the electric field.

1.39 Why knee voltage for silicon is higher than that of germanium?

[ESE-2018]

Ans. Because silicon has higher bandgap (1.1 eV) compared to germanium (0.72 eV).

1.40 Name 5 solid state devices. [ESE-2018]

Ans.
(i) Semiconductor diode
(ii) Transistor
(iii) Solar cell
(iv) Microprocessor chip
(v) LED and LASER

1.41 What are different types of diodes? What is their use, construction and working principle?

[ESE-2019]

Ans. They are: Schottky, Zener, LED, photo diode, PIN, varactor.

Schottky diode: It is used because of lower recovery time.

Zener diode: It is used in voltage regulation applications.

LED, Photodiode: It is used in optical applications.

PIN: It is used in switching at microwave frequencies.

Varactor diode: It is used for the generation of FM.

1.42 What is mobility?

Ans. The mobility of a charge carrier is defined as the drift velocity of charge carrier per unit electric field. Units $\rightarrow m^2/V\text{-sec}$.

[ESE-2014, 2019]

1.43 What is Hall effect? What is its application?

[ESE-2019]

Ans. **Hall Effect :** When a magnetic field is applied perpendicular to the direction of flow of charge carriers, in a **semiconductor** material, charge carriers experience a force transverse to the direction of the applied magnetic field and carrier flow. This **effect** is known as **Hall effect**.

Applications : **Hall Effect** is used to find whether a **semiconductor** is *n*-type or *p*-type. **Hall Effect** is used to find carrier concentration. **Hall Effect** is used to calculate the mobility of charge carriers

1.44 What is intrinsic and extrinsic semiconductor?

[ESE-2019]

Ans. An intrinsic semiconductor material is chemically very pure and possesses poor conductivity. It has equal number of negative carriers (electrons) and positive carriers (holes) and extrinsic semiconductor is an improved intrinsic semiconductor with a small amount of impurities added by a process, known as doping, which alters the electrical properties of the semiconductor and improves its conductivity. Depending on whether the added impurities have "extra" electrons or "missing" electrons determines how the bonding in the crystal lattice is affected and therefore how the material's electrical properties change.

1.45 What are direct and indirect band gap semiconductors?

[ESE-2005, 2015, 2020]

Ans. **Direct bandgap semiconductors:**

Those materials for which maximum of valence band and minimum of conduction band lie for same value of k, called direct bandgap materials (i.e. satisfies the condition of energy and momentum conservation). For example: GaAs, InP, CdS etc.

Indirect bandgap semiconductors:

Those materials for which maximum of valence band and minimum of conduction band do not occur at same value of k, called indirect bandgap materials. For example: Si and Ge

1.46 Effective mass of electron or hole – which one is more?

[ESE-2020]

Ans. The effective mass of electrons is not always less than the effective mass of holes. It depends on the semiconductor. For Si, the effective mass of hole is greater whereas for GaAs, effective mass of electron is greater. This is true when no conduction taking place.

1.47 What is effective mass? Why is the effective mass of electrons different from that of holes?

[ESE-2017, 2020]

Ans. The effective mass is the mass that it seems to have when responding to forces, or the mass that it seems to have when interacting with other identical particles.

- The effective mass is a quantity that is used to simplify band structures by modeling the behaviour of a free particle with that mass.

- The effective mass is a result of electron interaction with the lattice, i.e., with phonons. Since the mobility of electron is greater than mobility of holes, electron spends less time in the interaction region. So, the effective mass of electron is different from that of holes.

1.48 How do you differentiate semiconductor, insulator and conductor on the basis other than energy gap?

[ESE-2016, 2021]

Ans. **Insulator:** Materials through which electricity cannot pass are called insulators. Plastic, glass, wood etc are the examples of insulators. The valence band of those material remains full of electrons. The conduction band of those material remains empty. The forbidden energy gap between the conduction band and the valence band is widest. The difference is more than 10 eV.

Conductors: In figure b shows the energy band of good conductor or metal. The valence band and the conduction band are attached here or overlap each other. There is no forbidden energy gap here so $E_g = 0$. At absolute zero temperature, a large number of electrons remain in the conduction band. The resistance of conductor is very low, a large number charge carriers are available here. So, the electricity can pass easily through the conductors.

Semiconductors: Semiconductors are those materials whose electrical conductivity is between conductors and insulators. The forbidden energy gap of a semiconductor is nearly same as insulator. The energy gap is narrower. The value of E_g =1.1 eV for silicon crystal and E_g = 0.7 eV for germanium at ok. It can easily overcome due to thermal agitation or light. A semiconductor remains partially full valence band and partially full conduction band at the room temperature. The conduction band remains completely empty in a semiconductor whereas the valence band remains full of electrons at absolute zero temperature. So, silicon and germanium are insulators at absolute zero temperature. On the other hand with the increasing of temperature the electrical conductivity of semiconductors increase.

1.49 What is Mass Action Law?

[ESE-2016, 2021]

Ans. Under thermal equilibrium the product of the free electron concentration and the free hole concentration is equal to a constant equal to the square of intrinsic the carrier concentration The intrinsic carrier concentration is a function of temperature.

The equation for the mass action law for semiconductors is:

$$np = ni^2$$

1.50 What is work function, semiconductor bonding, and where do emitted electrons go?

[ESE-2025]

Ans. Work function is the minimum energy required to liberate an electron from a material's surface into free space, while atoms in a semiconductor crystal are bound together by covalent bonds. Once an electron absorbs sufficient energy exceeding the work function, it escapes the lattice into the vacuum energy level as a free electron.

1.51 What is a vacuum level/band?

[ESE-2025]

Ans. The vacuum level represents the energy state of a completely free electron located just outside the material surface with zero kinetic energy. It serves as the absolute baseline reference in solid-state physics for measuring electron affinity and work function.

1.52 What are semiconductors and how do they differ from metals?

[ESE-2025]

Ans. Semiconductors are materials with electrical conductivity falling between conductors and insulators, featuring a finite bandgap that can be altered via doping or temperature. Unlike metals, which possess overlapping valence and conduction bands with infinite free electrons, semiconductors require thermal or optical energy to promote electrons across their forbidden energy gap.

1.53 What are intrinsic and extrinsic semi-conductors?

[ESE-2025]

Ans. Intrinsic semiconductors are pure crystalline semiconductor materials containing equal concentrations of thermally generated electrons and holes. Extrinsic semiconductors are formed by intentionally introducing impurity atoms (dopants) to heavily skew carrier concentrations, creating *n*-type or *p*-type materials.

1.54 What are empty states and donor ions in semiconductors?

[ESE-2025]

Ans. Empty states refer to unoccupied energy levels in the conduction band where electrons can freely move to conduct electricity. A donor ion is a positively charged pentavalent impurity atom that has donated its fifth valence electron to the conduction band.

1.55 Why did the semiconductor industry transition from Germanium (Ge) to Silicon (Si)?

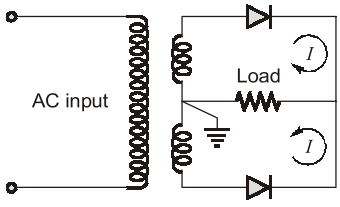
[ESE-2025]

Ans. Silicon is vastly preferred over germanium because it is earth-abundant, forms a chemically stable native oxide (SiO_2), and possesses a wider bandgap. This wider bandgap allows silicon devices to operate reliably at much higher temperatures with significantly lower reverse leakage currents.

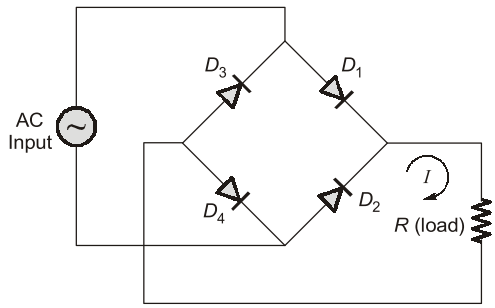
2. Diode

2.1 Draw diagram of full wave rectifier and bridge rectifier?

Ans.



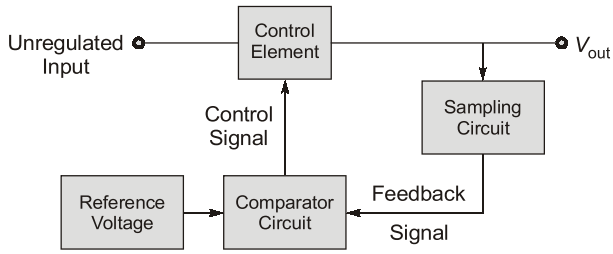
Full Wave Rectifier



Bridge Rectifier

2.2 What is a regulator? What are the blocks in a regulator?

Ans. A voltage regulator is a stabilizer that is designed to stabilize a voltage level. It is used to regulate or vary the output voltage of the circuit and to keep the output voltage constant at the desired value inspite of variations in the supply voltage or load current.



Series Voltage Regulator

2.3 Why do you call a charger as charger even though it is regulating voltage?

Ans. Cellphone chargers are simple AC to DC converters, i.e., they take a regular AC supply of 220 Volts and give a constant DC output voltage of around 5 V. Their utility is to charge the battery hence the name charger.

2.4 What is a rectifier?

Ans. A rectifier changes alternating current into unidirectional current. This process is called rectification. The three main types of rectifier are the half-wave, full-wave, and bridge. A rectifier is the opposite of an inverter, which changes direct current into alternating current.

HWR: The simplest type is the half-wave rectifier, which can be made with just one diode. When the voltage of the alternating current is positive, the diode becomes forward-biased and current flows through it. When the voltage is negative, the diode is reverse-biased and the current stops. The result is a clipped copy of the alternating current waveform with only positive voltage, and an average voltage that is one third of the peak input voltage. This pulsating direct current is adequate for some components, but others require a more steady current. This requires a full-wave rectifier that can convert both parts of the cycle to positive voltage.

FWR: The full-wave rectifier is essentially two half-wave rectifiers, and can be made with two diodes and an earthed centre tap on the transformer. The positive voltage half of the cycle flows through one diode, and the negative half flows through the other. The centre tap allows the circuit to be completed because current cannot flow